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DEVELOPMENT OF QUALITY ASSURANCE TRAINING MANUAL  
TO ASSIST IN ESTABLISHING SOUNDNESS REQUIREMENTS  
FOR ALUMINUM AND STEEL CASTINGS.

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by WALTER F. WOLF AND NELVIN V. PHYTILAS  
SALVATORE, B. CATALANO AND DON MATICHUK

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U.S. ARMY TANK-AUTOMOTIVE  
RESEARCH AND DEVELOPMENT COMMAND  
Warren, Michigan 48090

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**TECHNICAL REPORT NUMBER 12256**

**DEVELOPMENT OF QUALITY ASSURANCE TRAINING MANUAL  
TO ASSIST IN ESTABLISHING SOUNDNESS REQUIREMENTS  
FOR ALUMINUM AND STEEL CASTINGS**

**BY**

**WALTER F. WULF AND MELVIN V. PHYTILA  
SALVATORE B. CATALANO AND DON MATICHUK**

**August 1978**

**ARMOR, MATERIAL APPLICATION AND TECHNOLOGY FUNCTION**

# ABSTRACT

Samples of aluminum and steel casting flaws most commonly experienced in production were selected to be radiographed in order to develop quantitative and descriptive picture images of various radiographic reference standards. Graphic illustrations of flaw size and flaw distribution for various radiographic reference standards were depicted by using radiographs and associated cross-sectional photo-macrographs. These graphic illustrations of radiographic levels of acceptance will provide meaningful design criteria for establishing realistic standards of acceptance for new material applications. This report also furnishes operational guidance to quality assurance and radiographic personnel in their normal on-the-job duties.

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## INTRODUCTION

Present soundness requirements for many military castings are being specified according to severity levels listed in various specifications. Standards are selected on the basis of their numerical rating, or as specified in a related specification without serious consideration of the type and degree of flaw permitted for each grade level. It was originally intended that reference radiographs be used to categorize designated standards according to the stress requirements of the casting. With this procedure many castings are produced to a greater soundness requirement than necessary; conversely, this procedure is too lenient for other highly critical castings and ultimately creates service problems.

In accordance with project authorization from U.S. Army Materials and Mechanics Research Center, the task of compiling a flaw correlation document was established under the Materials Testing Technology Program. The effort was determined necessary to greatly assist the human judgement presently involved in designating casting soundness requirements.

## OBJECT

The object of this task is to provide a document which illustrates flaw correlation with radiographic images to assist design engineers in the proper selection of casting soundness requirements.

## SUMMARY

Typical flaw specimens of varying severity levels, presently encountered in aluminum and steel castings, were selected from representative components obtained from government and commercial sources. Flaw severity levels were graded radiographically to existing military and ASTM reference standards and categorized according to casting size and thickness. Photo-macrographs of flaw cross-sections were correlated with radiographic images to illustrate the actual relationship of flaw size to the casting area under evaluation.

## CONCLUSIONS

The completion of this document provides design engineers with flaw correlation data which will assist in more accurately selecting radiographic soundness requirements on future castings. This document will also furnish operational guidance to quality assurance and radiographic personnel in their normal on-the-job duties.



### TEST MATERIALS

1. Scrapped steel armor castings.
2. Scrapped aluminum castings of 355, 356 and special hi-strength Kaiser K01 alloy.
3. Industrial x-ray film of various sizes, medium grain, fine grain, and extra-fine grain.
4. Commercial photographic copy film, size 4 x 5 inches.
5. Photographic projection print paper.

### TEST EQUIPMENT

1. Industrial x-ray machine, 1000KVP, 3MA capacity
2. Industrial x-ray machine, 250KVP, 10MA capacity
3. Industrial x-ray machine, 140KVP, 2MA capacity
4. Industrial x-ray machine, 25KVP, 5MA capacity
5. Commercial 4 x 5 inch View camera
6. Commercial 4 x 5 condenser type photographic enlarger
7. Photographic reproduction printing equipment
8. Lithographic printing equipment

### TEST PROCEDURE

1. The procedure followed during the program was as follows:
  - a. Radiographic evaluation
  - b. Metallographic evaluation
  - c. Selection of standards for flaw correlation
  - d. Reproduction of selected standards

2. Following is a brief description of each procedure:

a. Radiographic evaluation:

Radiography of approximately 20 each aluminum and steel armor castings was performed in accordance with MIL-STD-453(1), dated 4 September 1963 (Radiographic Inspection). A minimum quality level of 2-IT, representing 1.4 percent sensitivity was maintained for all exposures. Several x-ray machines and a variety of radiographic exposure techniques were employed.

b. Metallographic evaluation:

Cross-sections were extracted from the selected specimens of most flaw types for verification of radiographic evaluation. Photo-macrographs were made of typical flaw conditions for correlation with reference standards.

c. Selection of standards for flaw correlation:

Grading of standards for flaw correlation were based on existing military and ASTM reference standards. Two levels of severity and in some flaws special gross conditions were selected to correlate the radiographic image with the flaw cross-sectional area.

d. Reproduction of selected standards:

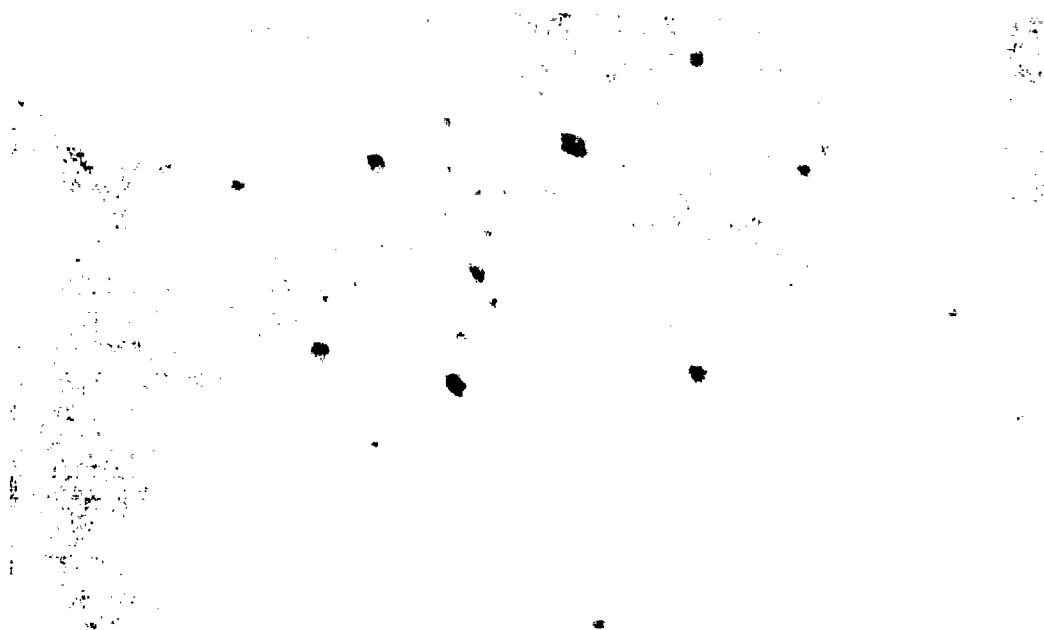
The original radiographs were photographically reproduced utilizing a conventional 4 x 5 inch view camera to copy the radiographic image as viewed with an eleven-tube fluorescent illuminator. Since photographic printing papers do not have the latitude of x-ray film, projection prints were made to allow the control necessary to obtain an authentic reproduction. Two methods of final reproduction were used in this document. The aluminum standards were reproduced by the photographic method; however, due to the exceptionally high cost of photographic reproduction, the steel standards were reproduced by the lithographic method.

## RESULTS AND DISCUSSIONS

The lack of flaw correlation data has led to a questionable procedure of specifying radiographic soundness requirements according to severity levels listed in specification without adequate radiographic and pictorial illustrations. The illustrated correlation data contained in

Figures 1 through 13 will enable recognition of flaw sizes and distribution as compared to casting cross-sectional appearance and assist in establishing more realistic standards of acceptance by design engineers and quality assurance personnel. This should ultimately result in greater reliability of aluminum and steel armor castings.

# STEEL CASTING FLAWS

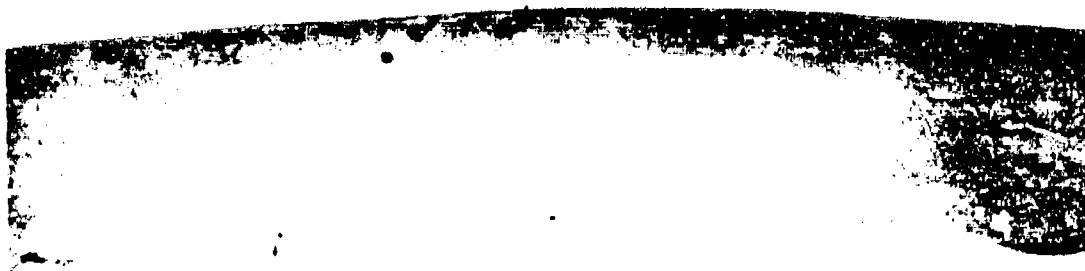


Radiographic image of gas porosity. Severity level shown compares with the following:

ASTM—E—446 — Grade 2

ASTM—E—186 — Grade 2

MIL—R—11469 — Acceptance is based on pore size and casting thickness. Amount shown meets Std. 2 for 1", and Std. 1 for 2" thickness.



Macrograph of partial casting cross section showing normal location of porosity near the surface. (unetched, actual size)

## EVALUATION OF GAS POROSITY IN CAST STEEL

Fig 1

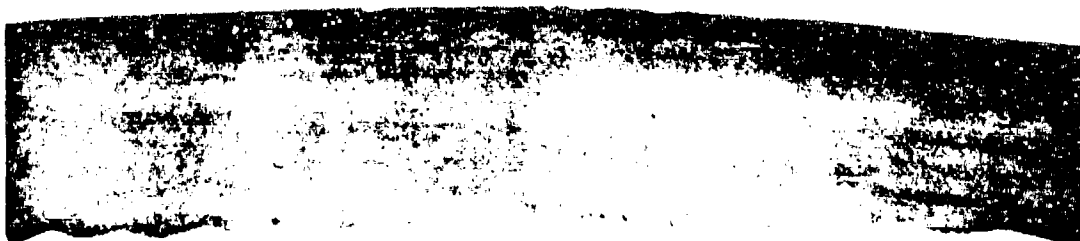


Radiographic image of gas porosity. Severity level shown compares with the following:

ASTM—E-446 — Grade 4

ASTM—E-186 — Grade 4

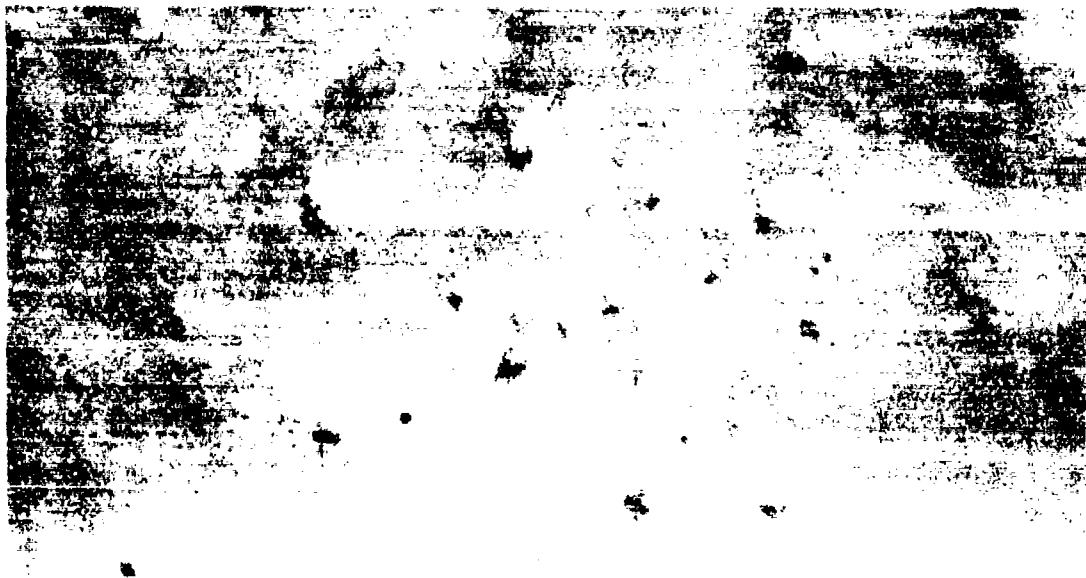
MIL—R-11469 — Acceptance is based on pore size and casting thickness. Amount shown meets Std. 3 for 1", and Std. 2 for 2" thickness.



Macrograph of partial casting cross section showing normal location of porosity near the surface. (unetched, actual size)

## EVALUATION OF GAS POROSITY IN CAST STEEL

Fig. 2



**Radiographic image of inclusions. Severity level shown compares with the following:**

**ASTM—E—446 — Grade 2**

**ASTM—E—186 — Grade 2**

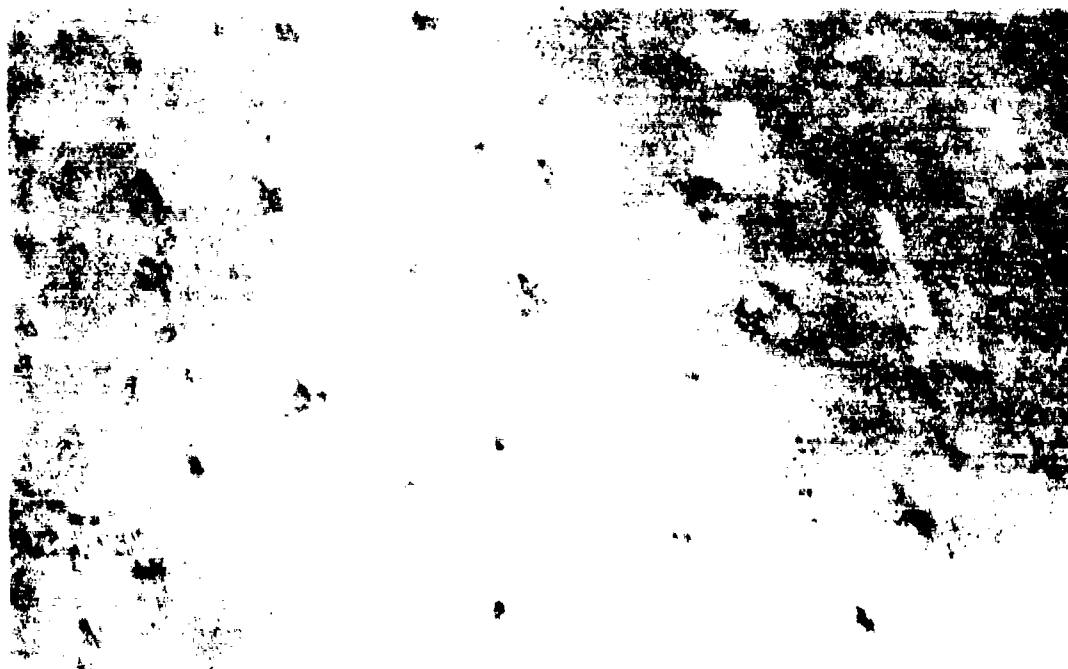
**MIL—R—11469 — Acceptance based on inclusion size and casting thickness. Amount shown meets Std. 2 for 1", and Std. 1 for 2" thickness.**



**Macrograph of partial casting cross section showing normal location of inclusions near the surface. (unetched, actual size)**

### **EVALUATION OF SAND AND SLAG INCLUSIONS IN CAST STEEL**

**Fig. 3**

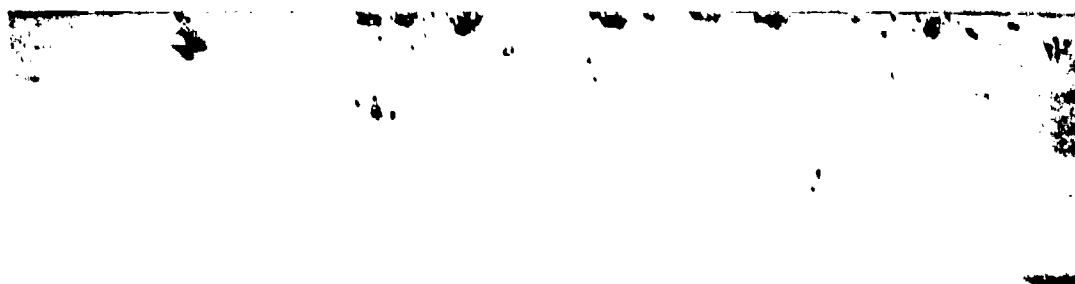


**Radiographic image of inclusions. Severity level shown compares with the following:**

**ASTM—E446 — Grade 5**

**ASTM—E186 — Grade 4**

**MIL—R—11469 — Acceptance based on inclusion size and casting thickness. Amount shown meets Std. 4 for 1" and Std. 3 for 2" thickness.**



**Macrograph of partial casting cross section showing normal location of inclusion near the surface. (unetched, actual size)**

**EVALUATION OF SAND AND SLAG INCLUSIONS IN CAST STEEL**

**FIG. 4**

# SHRINKAGE — (DENDRITIC)



RADIOGRAPHIC IMAGE OF DENDRITIC SHRINKAGE IN CAST STEEL  
2 INCHES THICK.

EVALUATION INCLUDED IN FIG. 5B.

Fig. 5A



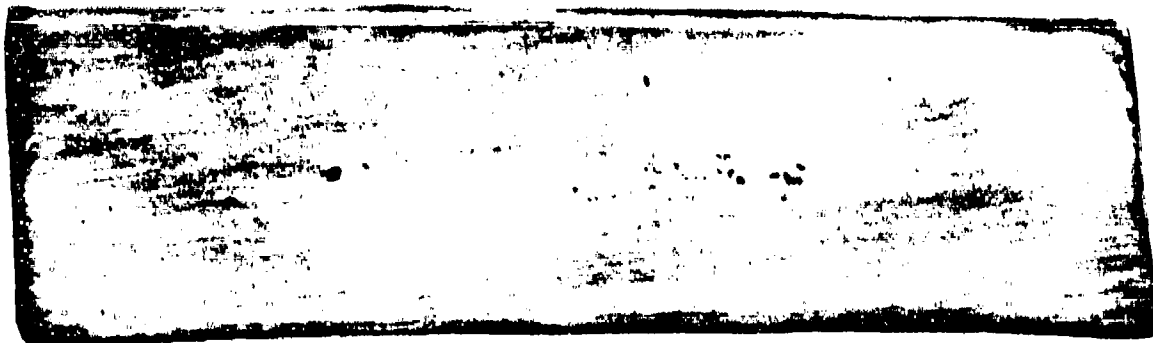
#### **EVALUATION OF FIG. 5A**

Severity level of the shrinkage shown in Fig. 5A compares with the following:

**ASTM—E—446 — Type CA — Grade 3**

**ASTM—E—186 — Type I — Grade 3**

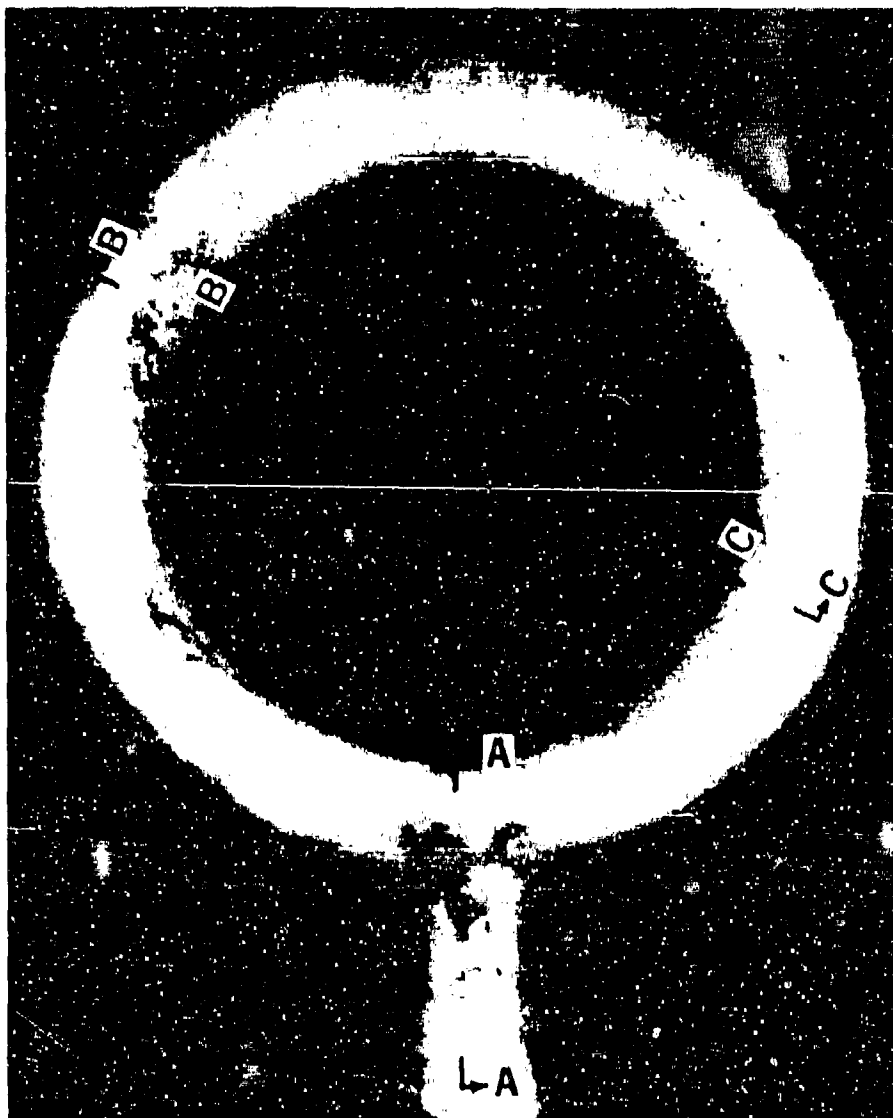
**MIL—R—11469 — Type B — Std 2**



**Macrograph of casting cross section AA, shown in Fig 5A, revealing severity and location of the shrinkage condition. (unetched, actual size)**

#### **EVALUATION OF DENDRITIC SHRINKAGE IN CAST STEEL 2 INCHES THICK**

**Fig. 5B**



RADIOGRAPHIC IMAGE OF INTERNAL SHRINKAGE IN CAST STEEL.

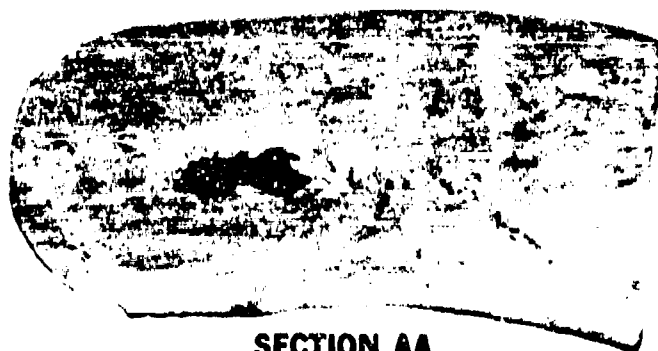
EVALUATION INCLUDED IN FIG. 6B.

Fig. 6A

## EVALUATION OF FIG. 6A

Severity level of shrinkage shown in Fig. 6A compares with the following:

SECT AA CAVITY	{	ASTM—E—446 — Fails to meet any grade
		ASTM—E—186 — Not applicable, too thin
		MIL—R—11469 — Std. 5 (judged as gas)
SECT BB & CC DENDRITIC	{	ASTM—E—446 — Type CA — grade 3
		ASTM—E—186 Not applicable, too thin
		MIL—R—11469 — Type C — Std. 2



SECTION BB

SECTION—CC

Marcographs of casting cross sections, shown in Fig 6A, revealing severity and location of shrinkage condition. (unetched, actual size)

## EVALUATION OF INTERNAL SHRINKAGE IN CAST STEEL

Fig. 6B



**RADIOGRAPHIC IMAGE OF DENDRITIC SHRINKAGE IN CAST STEEL  
1 1/4 INCHES THICK. EVALUATION IS SHOWN IN FIG. 7B.**

**Fig. 7A**

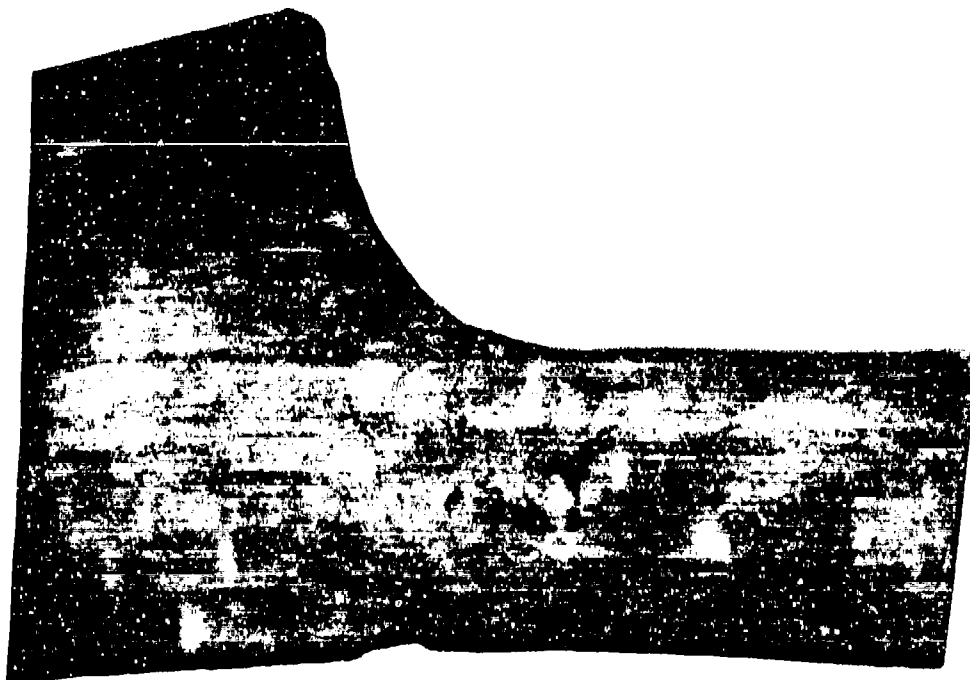
### **EVALUATION OF FIG. 7A**

**Severity level of shrinkage shown in Fig. 7A compares with the following:**

**ASTM—E—446 — Type CB — Grade 5**

**ASTM—E—186 — Not applicable, too thin**

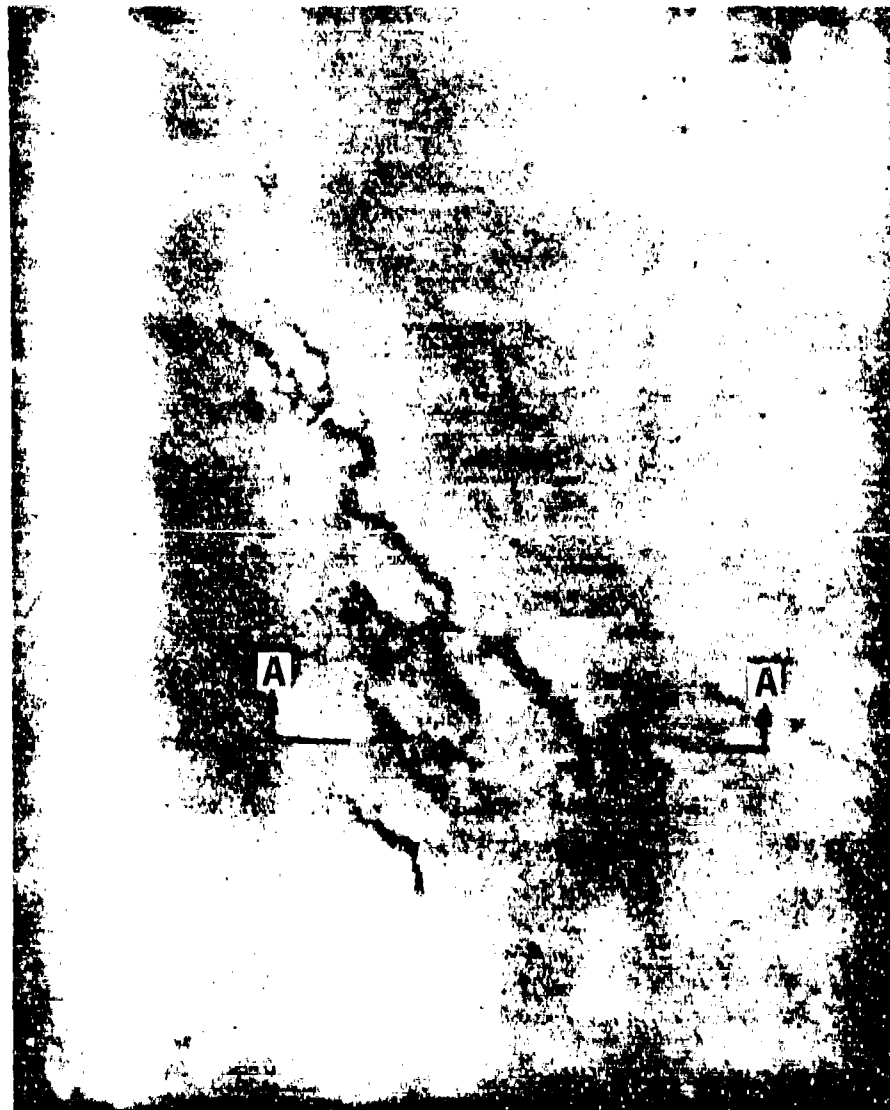
**MIL—R—11469 — Type C — Std. 3**



**Macrograph of casting cross section — AA, shown in Fig 7A, revealing severity and location of the shrinkage condition. (unetched, actual size)**

### **EVALUATION OF DENDRITIC SHRINKAGE IN CAST STEEL 1¾ INCHES THICK.**

**Fig. 7B**



Radiographic image of dendritic shrinkage in 2½" thickness of steel. Severity level shown compares with the following:

ASTM—E—446 — Not applicable, too thick

ASTM—E—186 — Type C — Std. 4

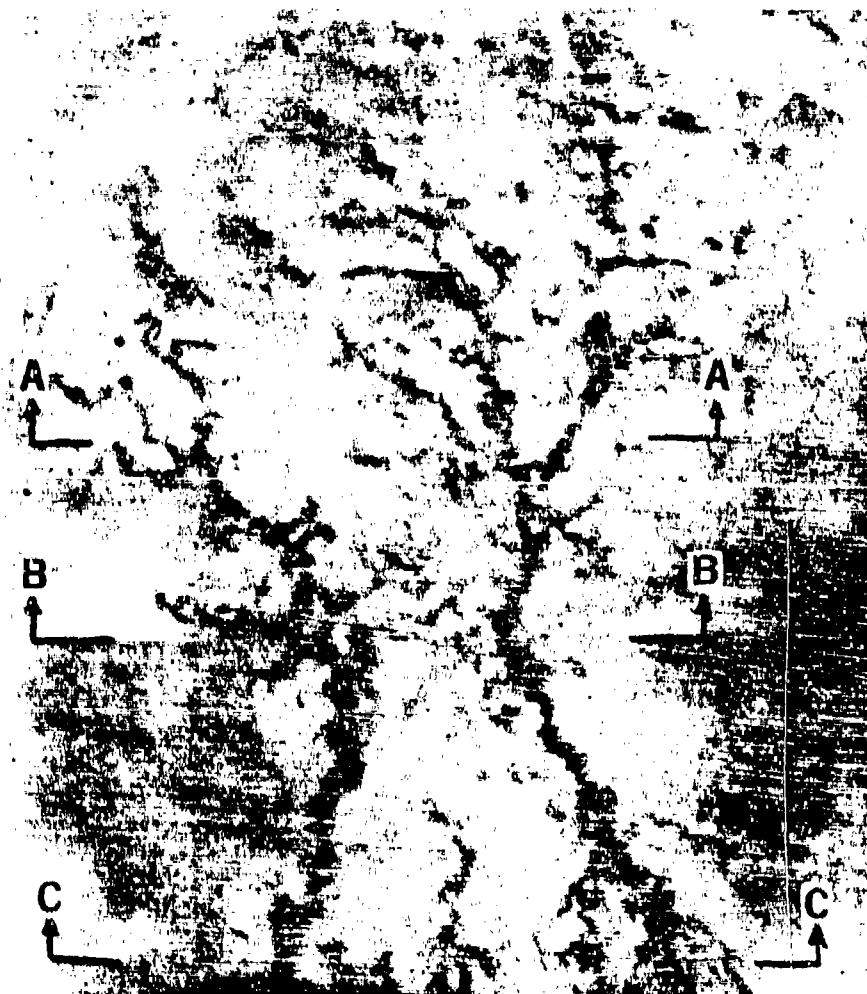
MIL—R—11469 -- Type C — Std. 3

Fig. 8A



**Macrograph of casting cross section, shown in Fig. 8A, revealing severity and location of shrinkage condition. (unetched, actual size)**

**Fig. 8B**



**RADIOGRAPHIC IMAGE OF DENDRITIC SHRINKAGE IN CAST STEEL  
2 INCHES THICK. EVALUATION SHOWN IN FIG. 9B.**

**Fig. 9A**



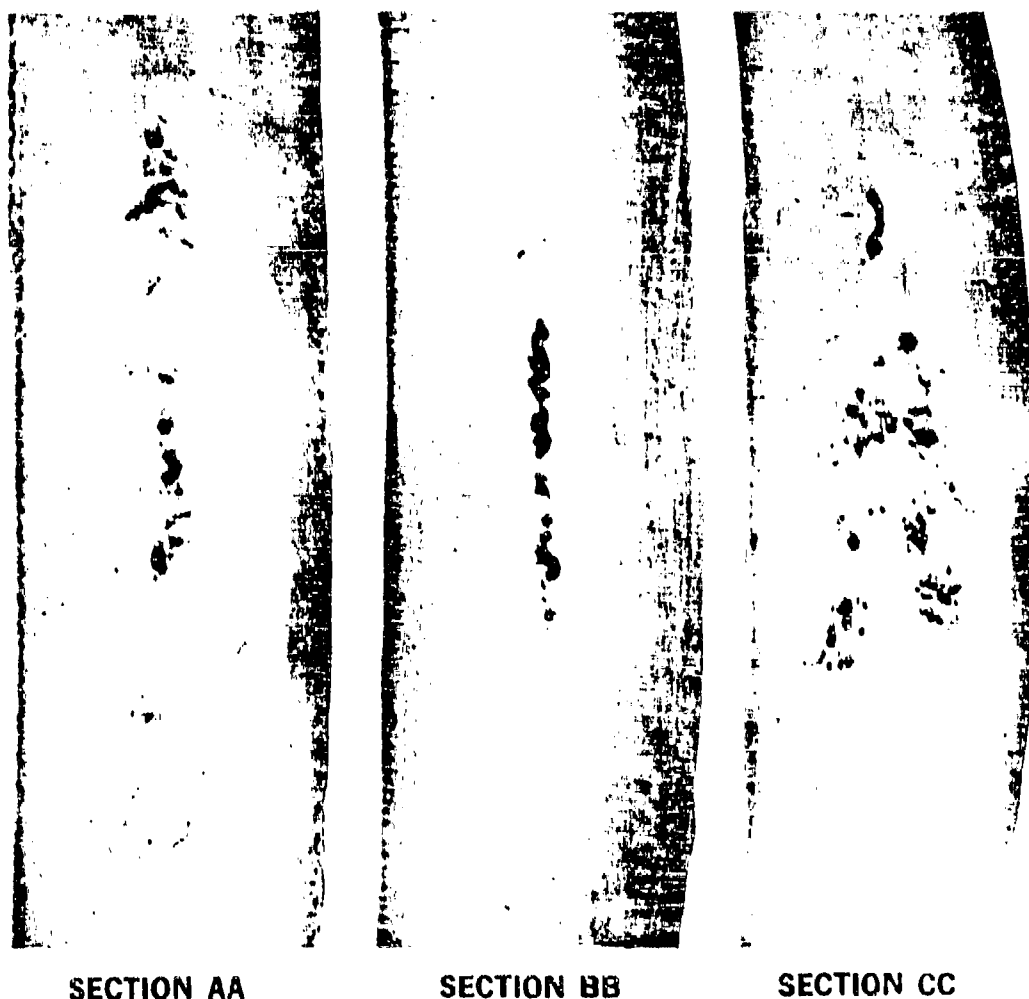
### **EVALUATION OF FIG. 9A**

Severity level of shrinkage shown in Fig. 9A compares with the following:

ASTM—E—446 — Exceeds Grade CB-5

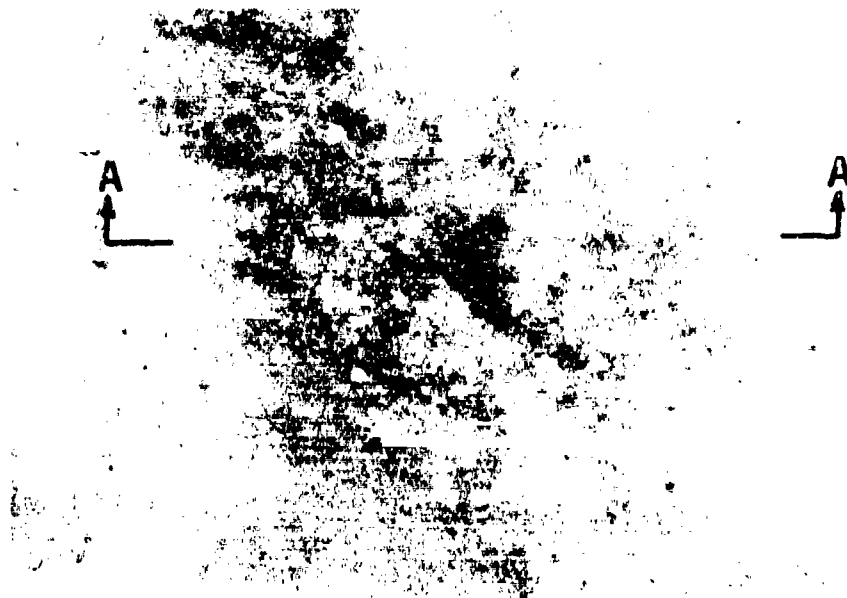
ASTM—E—186 — Type 2 — Grade 5

MIL—R—11469 — Type C — Std. 4



Macrographs of casting cross sections, shown in Fig. 9A, revealing severity and location of shrinkage condition. (unetched, actual size)

Fig. 9B



**Radiographic image of sponge shrinkage in 1½" steel. Severity level shown compares with the following:**

**ASTM—E—446 — Type CC, Grade 4**

**ASTM—E—186 — Not applicable, too thin**

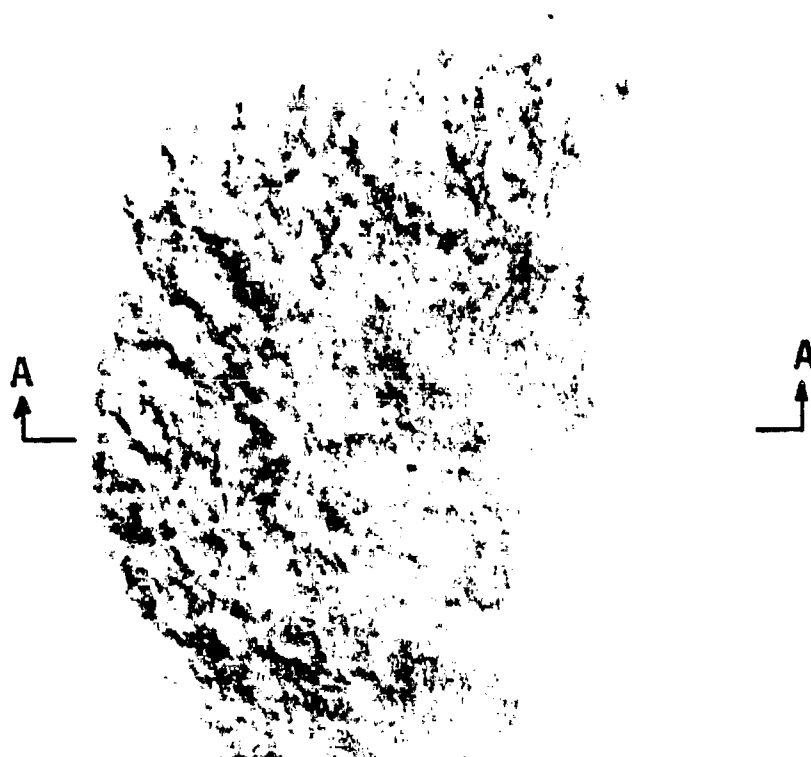
**MIL—R—11469 — Type D — Std. 3**



**Macrograph of casting cross section-AA showing severity and location of shrinkage condition. (unetched, actual size)**

**EVALUATION OF SPONGE SHRINKAGE IN CAST STEEL 1½ INCHES THICK.**

**Fig. 10**



**RADIOGRAPHIC IMAGE OF SPONGE SHRINKAGE IN CAST STEEL 1½ INCHES THICK. EVALUATION INCLUDED IN FIG. 11B.**

**Fig. 11A**

### **EVALUATION OF FIG. 11A**

Severity level of the shrinkage shown in Fig. 11A compares with the following:

ASTM—E—446 — Type CC — Grade 5

ASTM—E—186 — Not applicable, too thin

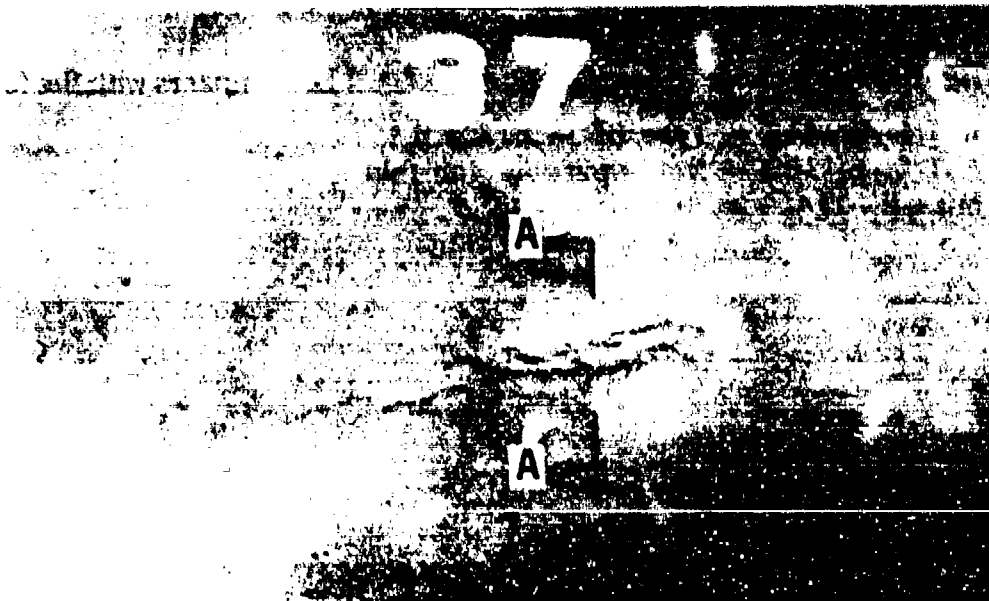
MIL—R—11469 — Type D — Std. 3



Macrograph of casting cross section AA, shown in Fig. 11A, revealing severity and location of the shrinkage condition. (unetched, actual size)

### **EVALUATION OF SPONGE SHRINKAGE IN CAST STEEL 1½ INCHES THICK.**

Fig. 11B



**Radiograph of a 3" hot tear in cast steel 2½ thick (Radiation angle 20°)**



**Same hot tears as above but radiation was more parallel with the tear. Severity evaluation shown in Fig. 12B.**

**Fig. 12A**

### **EVALUATION OF FIG. 12A**

**Severity level of the tear shown in Fig. 12A compares with the following:**

**ASTM—E—446 — Not applicable, too thick**

**ASTM—E—186 — Level 4**

**MIL—R—11469 — Std. 4**



**Macrograph of casting cross section AA, shown in Fig. 12A, revealing severity and location of the tear. (unetched, actual size)**

**EVALUATION OF HOT TEAR IN CAST STEEL 2½ INCHES THICK.**

**Fig. 12B**



Radiograph of a 5" hot tear in cast steel 2½ inches thick. Severity level is as follows:

ASTM—E—446 — Not applicable, too thick

ASTM—E—186 — Level 5

MIL—R—11468 — Std. 5

EVALUATION OF HOT TEAR IN CAST STEEL 2½ INCHES THICK.

Fig. 13A



**Macrograph of casting section AA shown in Fig. 13A, revealing cross sectional extent of the tear. (unetched, actual size)**

**EVALUATION OF HOT TEAR IN CAST STEEL 2½ INCHES THICK.**

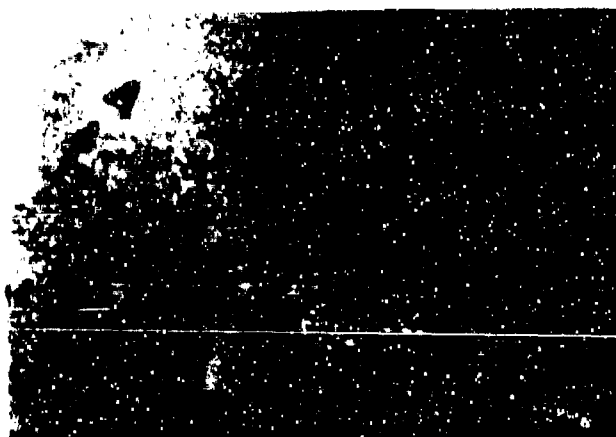
**Fig. 13B**



## ALUMINUM CASTING FLAWS

This edition of the report is updated to include 22 figures- actual photographs- of the various aluminum casting flaws under study. The pictures will permit engineers and technicians to get a realistic perception for material integrity and flaw classification in these thickness ranges of aluminum.

# **GAS HOLES**



**Actual Size Radiograph - Material Thickness 5/16"**  
**Meets Std. 4 of ASTM E-155**



**Macrograph of Cross Section AA Exposing the Flaw**  
**4X Magnification- Unetched**

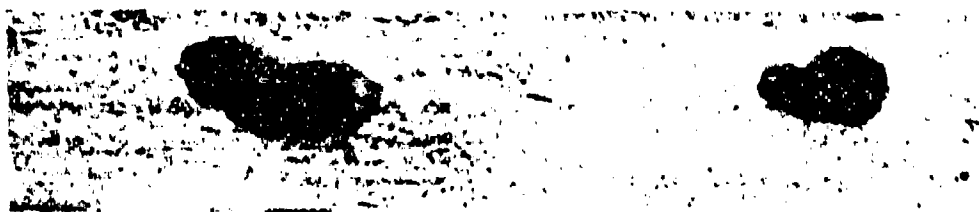
**EVALUATION OF GAS HOLES IN CAST ALUMINUM**

**Figure 1A**

## GAS HOLES

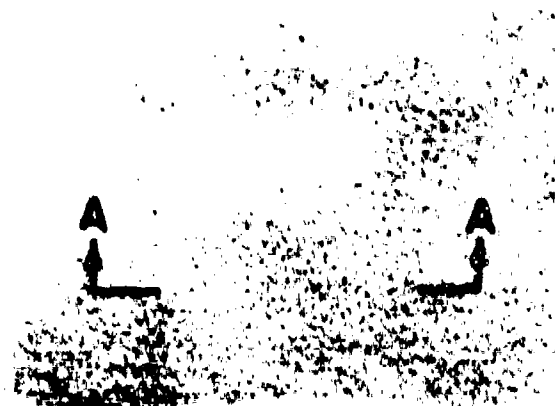


Actual Size Radiograph - Material Thickness 5/16"  
Meets Std. 7 of ASTM E-155

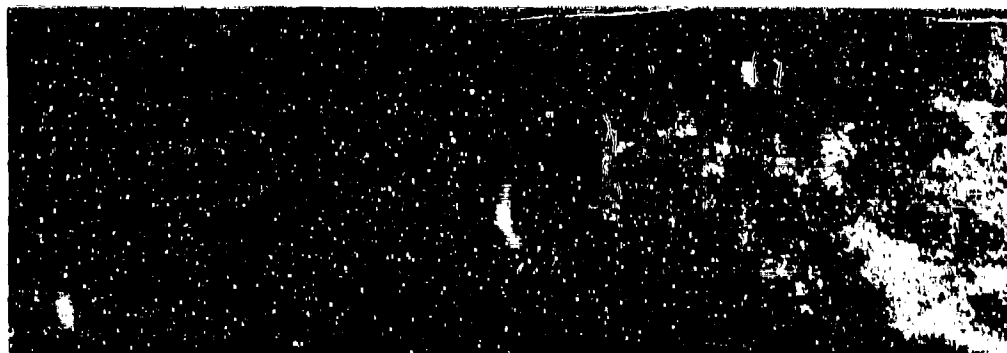


Macrograph of Cross Section AA Exposing the Flaw  
4X Magnification- Unetched

## GAS POROSITY - ROUND



Actual Size Radiograph - Material Thickness 1/4"  
Meets Std. 2 of ASTM E-155



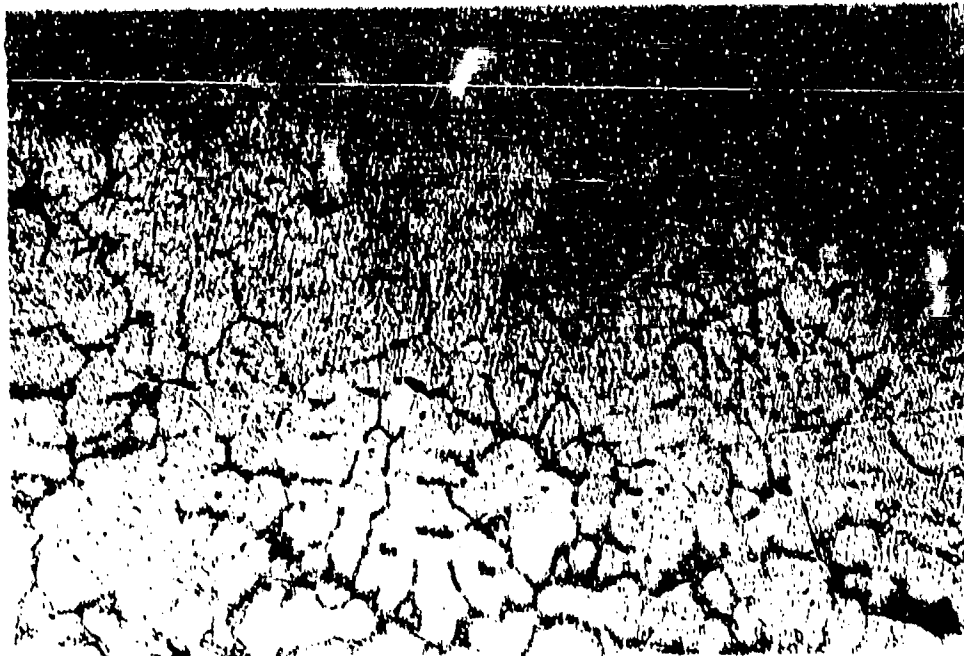
Micro-Radiograph of a .025" Thick Specimen Adjacent  
to Cross Section AA Showing a Single Layer View of the  
Porous Condition at 10X Magnification.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

## GAS POROSITY - ROUND



Macrograph of Cross Section AA (Fig. 2A) Showing  
Std. 2 Porosity at 4X Magnification. Unetched



Micrograph of Cross Section AA (Fig. 2A) Showing the  
Porous Condition at 100X Magnification - Kellers Etch.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 2B

## GAS POROSITY - ROUND



Actual Size Radiograph - Material Thickness  $\frac{3}{8}$ "  
Meets Std. 4 of ASTM E-155



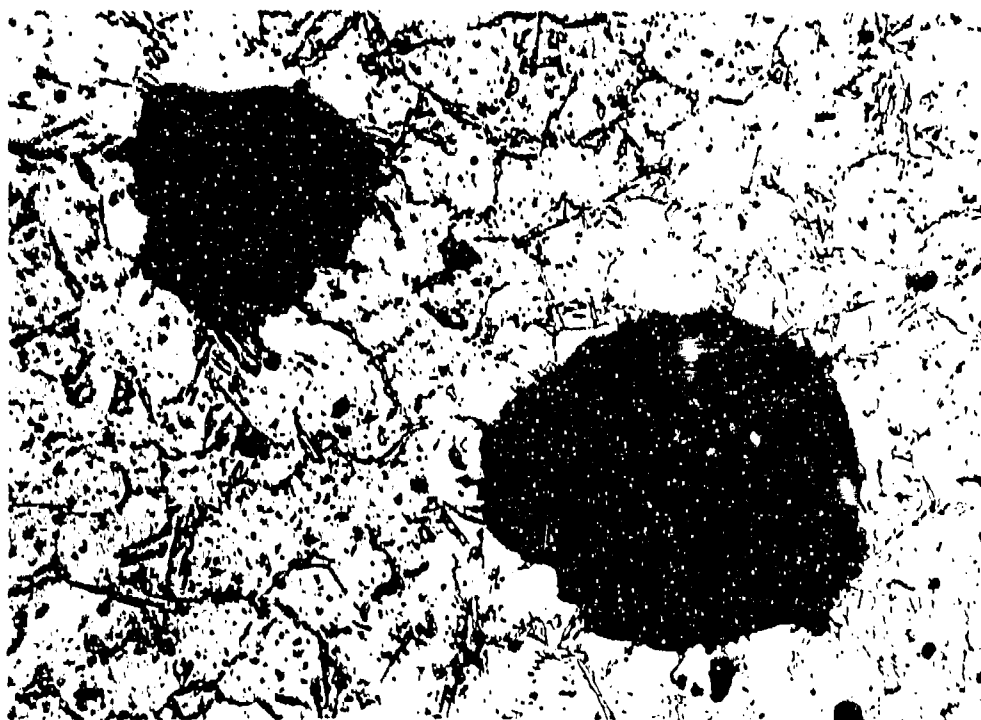
Micro-Radiograph of a .025" Thick Specimen Adjacent to  
Cross Section AA Showing a Single Layer View of the Porous  
Condition at 10X Magnification.

### EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 3A

## GAS POROSITY - ROUND

Macrograph of Cross Section AA (Fig.3A) Showing Std.4 Porosity at 4X Magnification - Unetched.



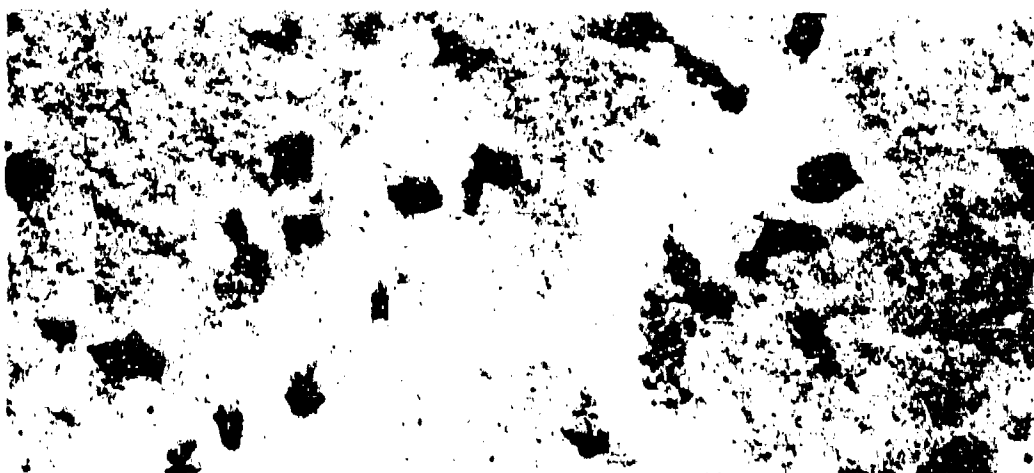
Micrograph of Cross Section AA (Fig.3A) Showing the Porous Condition at 100X Magnification - Kellers Etch.

EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 3B

## GAS POROSITY - ROUND

Actual Size Radiograph - Material Thickness 1/4"  
Meets Std. 6 of ASTM E-155



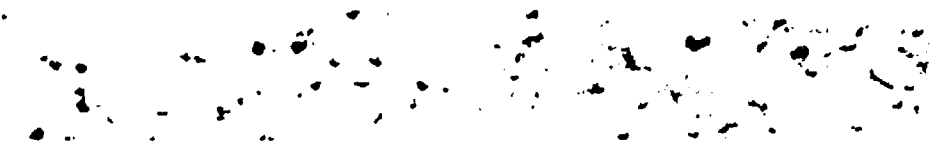
Micro-Radiograph of a .025" Thick Specimen Adjacent to  
Cross Section AA Showing a Single Layer View of the Porous  
Condition at 10X Magnification.

EVALUTION OF GAS POROSITY-ROUND IN CAST ALUMINUM

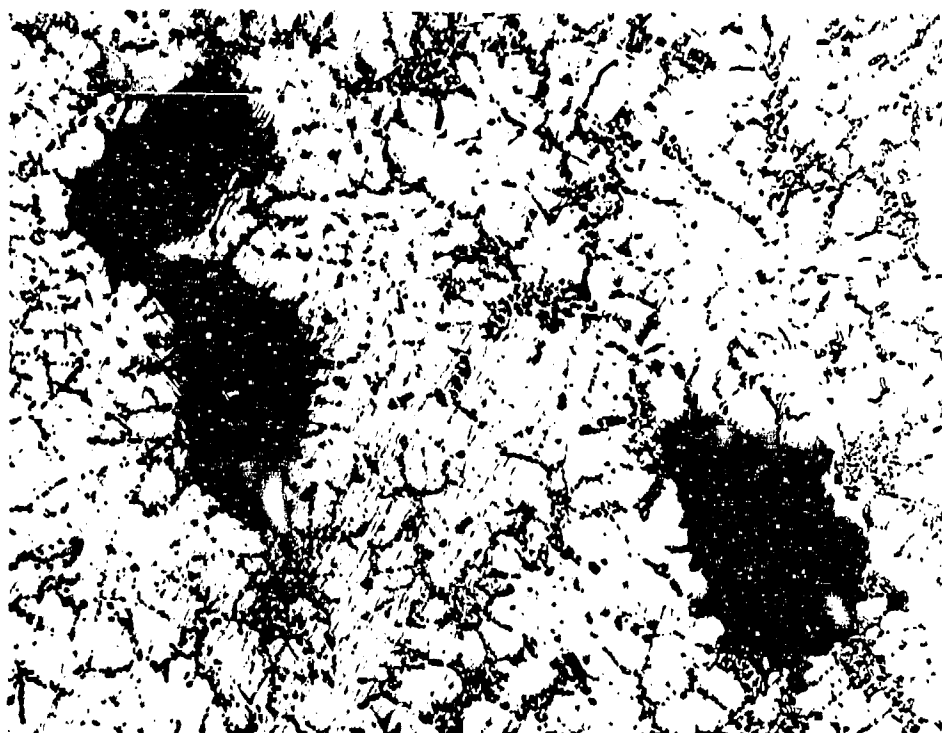
Figure 4A



## GAS POROSITY - ROUND



Macrograph of Cross Section AA (Fig. 4A) Showing  
Std. 6 Porosity at 4X Magnification - Unetched



Micrograph of Cross Section AA (Fig. 4A) Showing  
the Porous Condition at 100X Magnification-Kellers Etch.

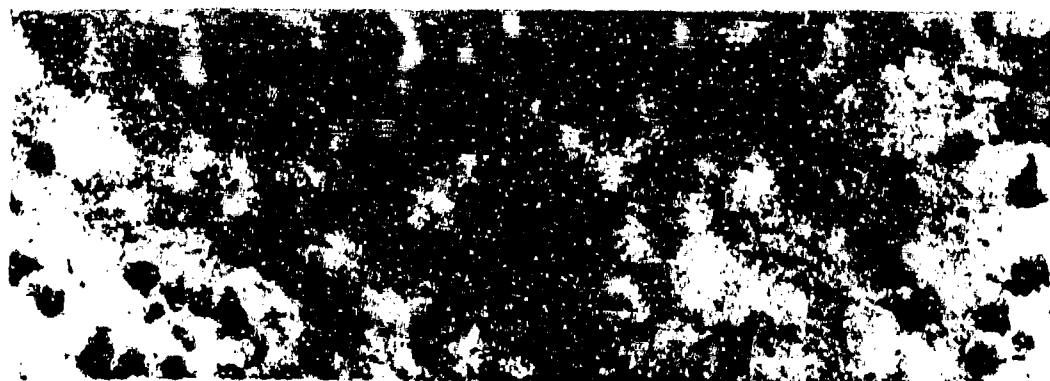
EVALUATION OF GAS POROSITY-ROUND IN CAST ALUMINUM

Figure 4B

## GAS POROSITY-ELONGATED



Actual Size Radiograph - Material Thickness  $1/4"$  &  $3/8"$   
Meets Std. 3 of ASTM E-155

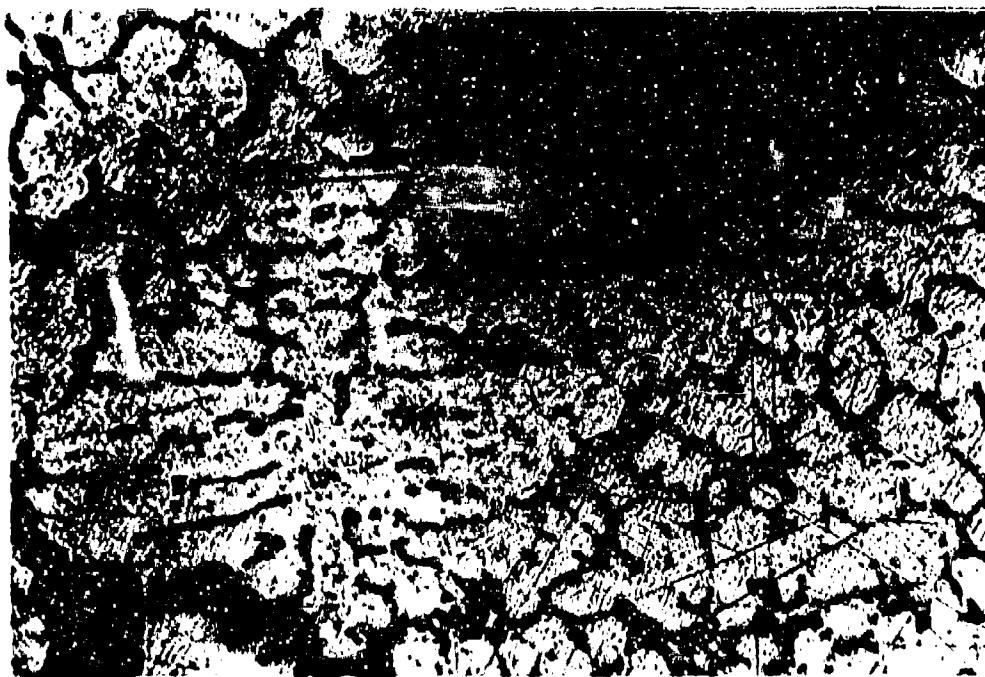


Micro-Radiograph of a  $.027"$  Thick Specimen Adjacent  
to Cross Section AA Showing a Single Layer View of the Porous  
Condition at 10X Magnification.

EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

## GAS POROSITY - ELONGATED

Macrograph of Cross Section AA (Fig.5A) Showing  
Std. 3 Porosity at 4X Magnification-Unetched.



Micrograph of Cross Section AA (Fig.5A) Showing the  
Porous Condition at 100X Magnification-Kellers Etch.

EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

Figure 5B

## GAS POROSITY - ELONGATED



Actual Size Radiograph - Material Thickness 1/2"  
Meets Std.6 of ASTM E-155



Micro-Radiograph of a .020" Thick Specimen Adjacent  
to Cross Section AA Showing a Single Layer View of the  
Porous Condition at 10X Magnification.

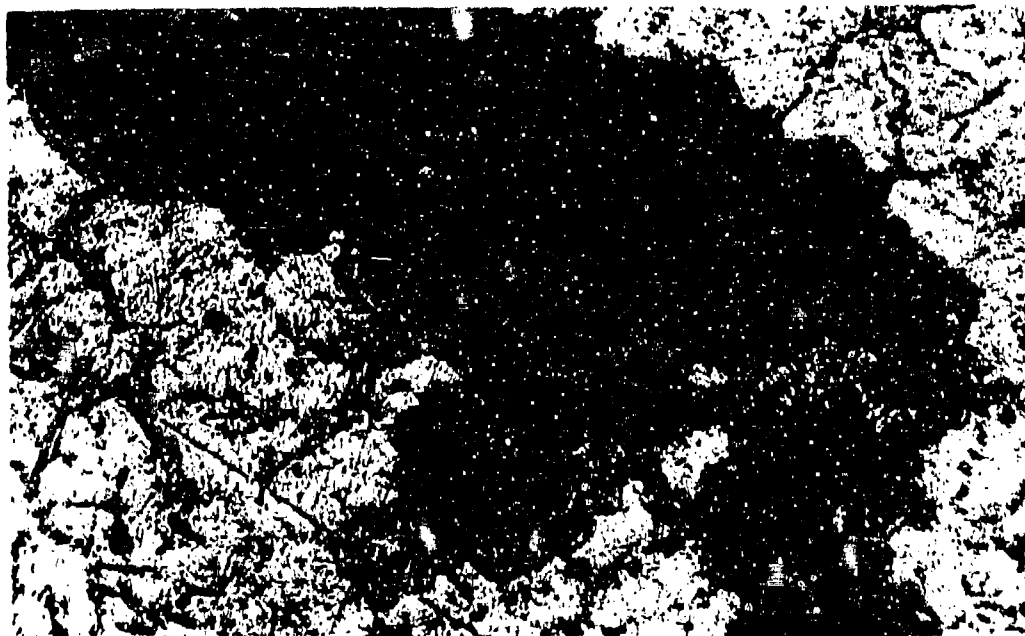
EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

Figure 6A

## GAS POROSITY - ELONGATED



Macrograph of Cross Section AA (Fig. 6A) Showing  
Std. 6 Porosity at 4X Magnification-Unetched.

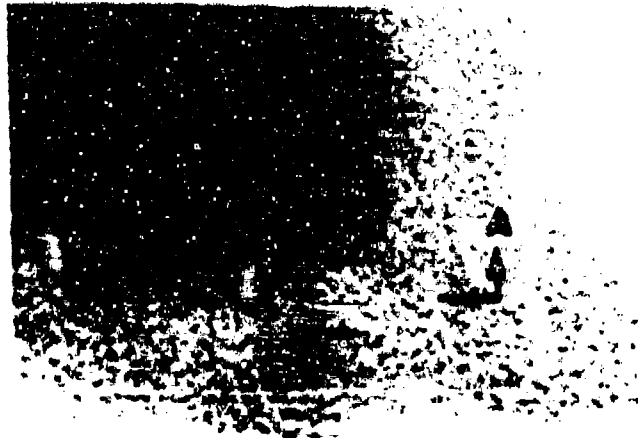


Micrograph of Cross Section AA (Fig. 6A) Showing the  
Porous Condition at 100X Magnification-Kellers Etch.

EVALUATION OF GAS POROSITY-ELONGATED IN CAST ALUMINUM

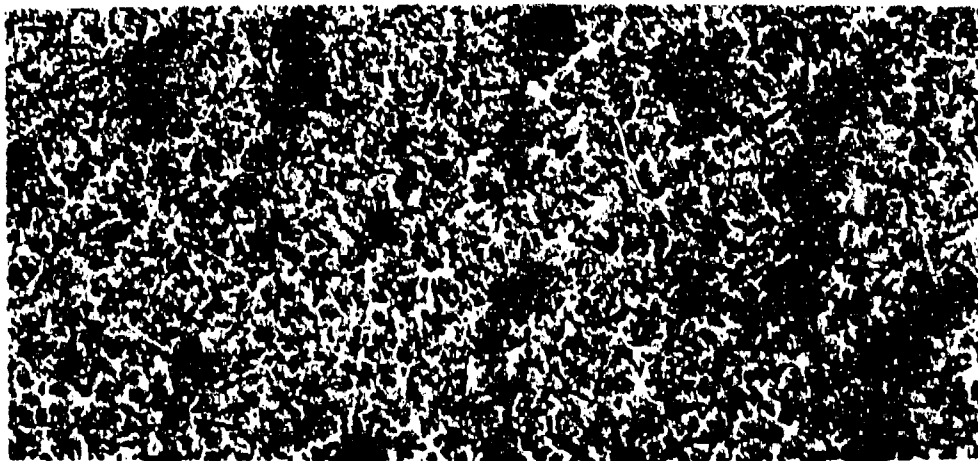
Figure 6B

## GRAIN BOUNDARY SHRINKAGE



Actual Size Radiograph - Material Thickness  $3/8$ "

This Condition is not included in ASTM E-155. It Appears Similar to, and Compares with Std.4 of Gas Porosity-Elongated.



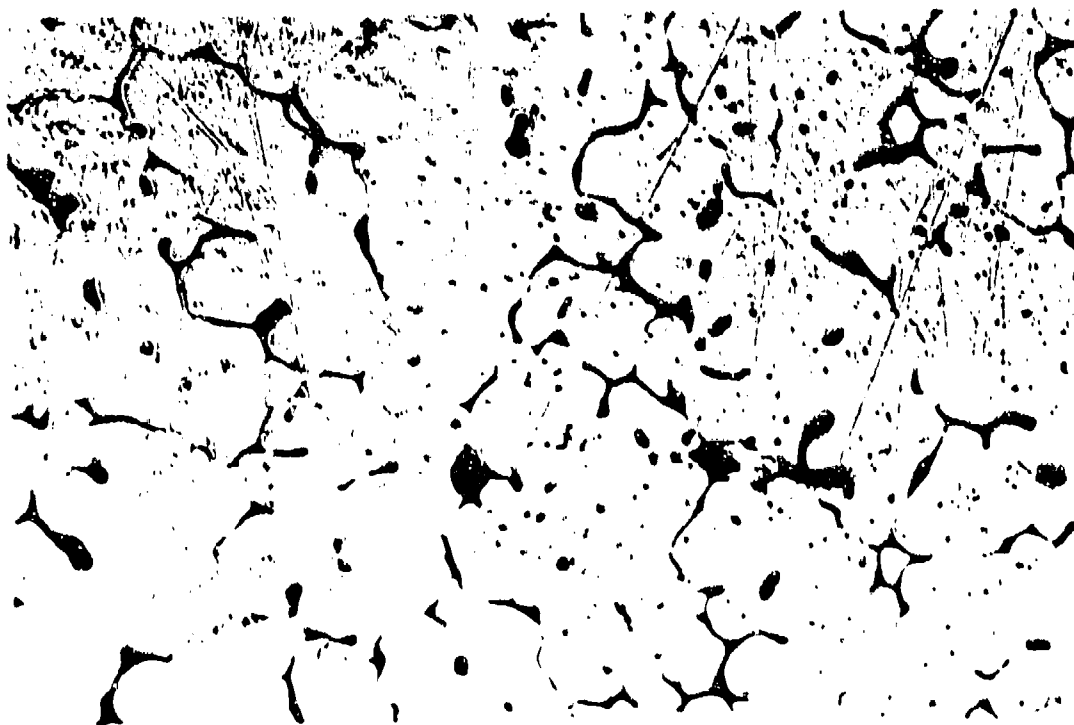
Micro-Radiograph of a .030" Thick Specimen Adjacent to Cross Section AA Showing a Single Layer View of the Shrinkage Condition at 10X Magnification.

EVALUATION OF GRAIN BOUNDARY SHRINKAGE IN HIGH STRENGTH CAST ALUMINUM.

# GRAIN BOUNDARY SHRINKAGE



Macrograph of Cross Section AA (Fig. 7A). No Evidence of the Shrink Condition is Visible at 4X Magnification - Unetched.



Micrograph of Cross Section AA (Fig. 7A) Showing the Shrink Condition at 100X Magnification - Kellers Etch.

EVALUATION OF GRAIN BOUNDARY SHRINKAGE IN HIGH STRENGTH CAST ALUMINUM.

## SHRINKAGE - CAVITY



Actual Size Radiograph - Material Thickness 1/4"  
Meets Std.3 of ASTM E-155



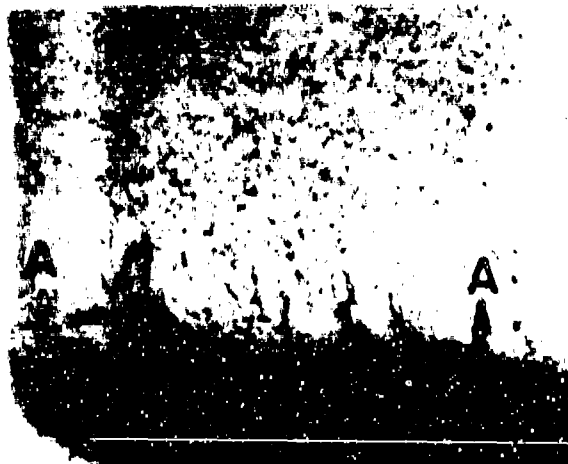
Macrograph of Cross Section AA Exposing the Flaw-  
4X Magnification - Unetched. Small Pores are Gas Porosity.

EVALUATION OF CAVITY TYPE SHRINKAGE IN CAST ALUMINUM

Figure 8



## SHRINKAGE - CAVITY



Actual Size Radiograph - Material Thickness 1/4"  
Meets Std.7 of ASTM E-155



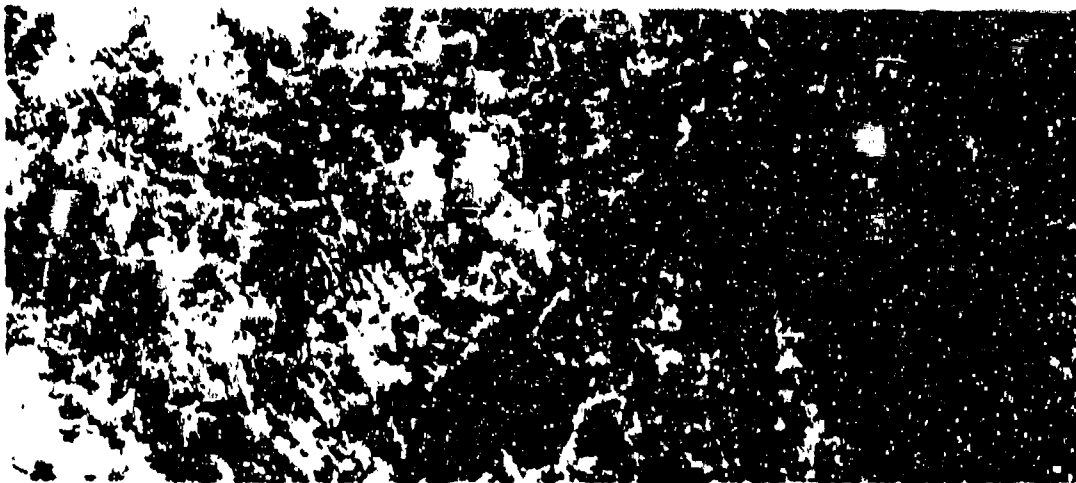
Macrograph of Cross Section AA Exposing the Flaw- 4X  
Magnification - Unetched. Small Pores are Gas Porosity.

EVALUATION OF CAVITY TYPE SHRINKAGE IN CAST ALUMINUM

## SHRINKAGE - SPONGE



Actual Size Radiograph - Material Thickness 7/8"  
Meets Std.4 of ASTM E-155



Micro-Radiograph of a .023" Thick Specimen Adjacent  
to Cross Section AA Showing a Single Layer View of the  
Shrinkage Condition at 10X Magnification.

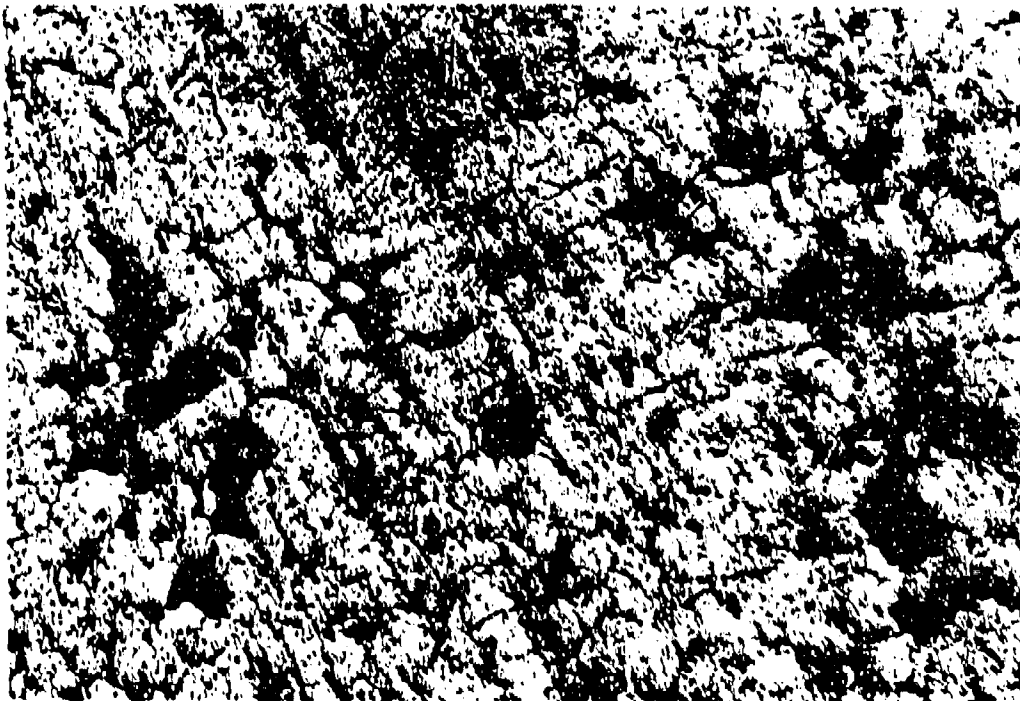
### EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

Figure 10A

## SHRINKAGE - SPONGE



Macrograph of Cross Section AA (Fig. 10A) Showing Std. 4 Shrinkage at 4X Magnification - Unetched.



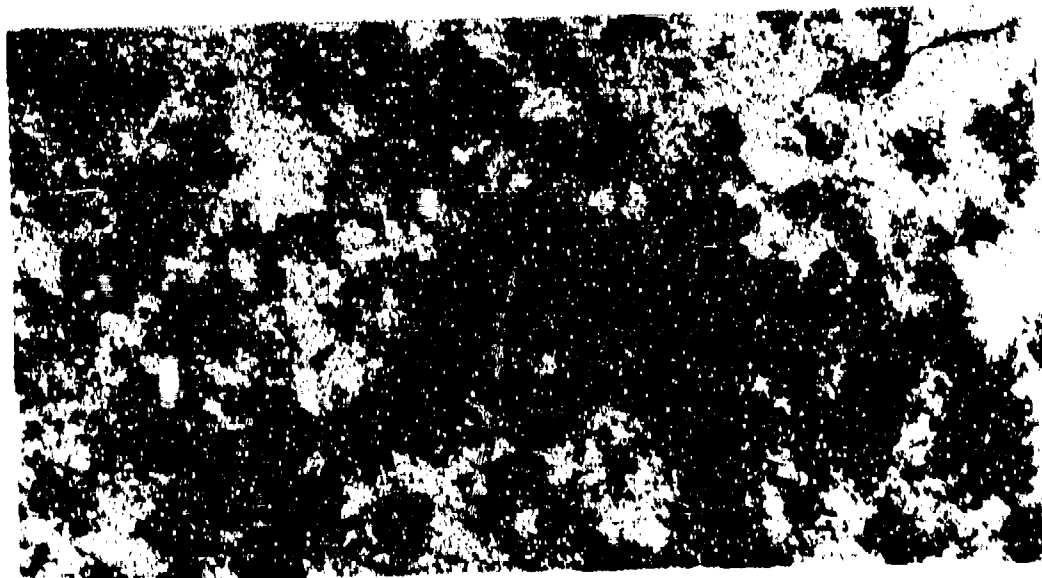
Micrograph of Cross Section AA (Fig. 10A) Showing the Shrinkage Condition at 100X Magnification - Kellers Etch.

EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

## SHRINKAGE - SPONGE



Actual Size Radiograph - Material Thickness 5/16"  
Meets Std.7 of ASTM E-155



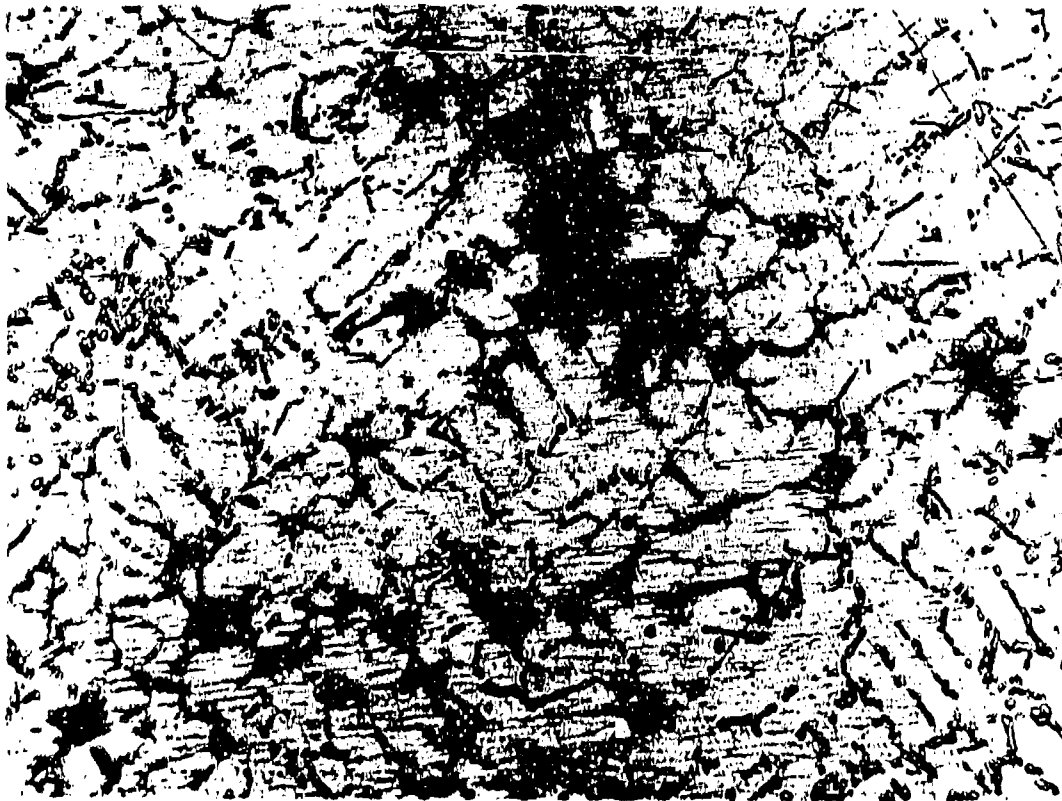
Micro-Radiograph of a .025" Thick Specimen  
Adjacent to Cross Section AA Showing a Single  
Layer View of the Shrinkage Condition at 10X  
Magnification.

EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

## SHRINKAGE - SPONGE



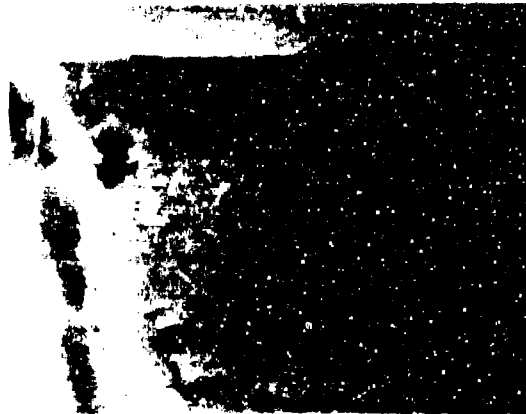
Macrograph of Cross Section AA (Fig. 11A) Showing Std. 7 Shrinkage at 4X Magnification - Unetched.



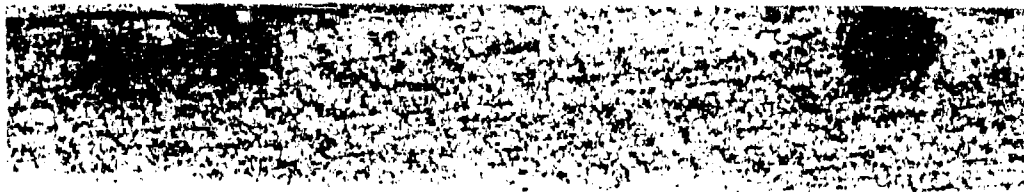
Micrograph of Cross Section AA (Fig. 11A) Showing the Shrinkage Condition at 100X Magnification - Kellers Etch.

EVALUATION OF SPONGE SHRINKAGE IN CAST ALUMINUM

## FOREIGN MATERIAL - LESS DENSE



Actual Size Radiograph - Material Thickness 5/16"  
Meets Std. 7 of ASTM E-155"



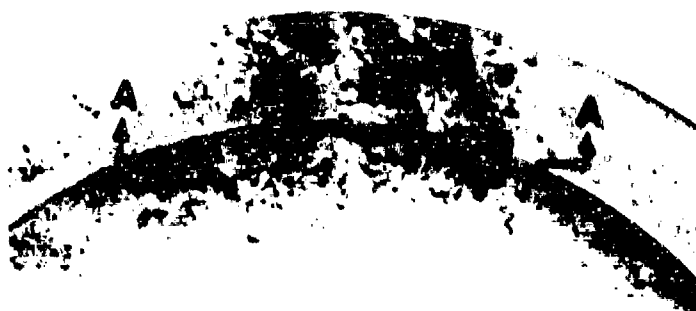
Macrograph of Cross Section AA Exposing the Flaw  
4X Magnification - Unetched



Macrograph of Cross Section BB Exposing the Flaw  
4X Magnification - Unetched

EVALUATION OF FOREIGN MATERIAL IN CAST ALUMINUM

## FOREIGN MATERIAL - LESS DENSE



Actual Size Radiograph - Material Thickness 5/8"  
Meets Std. 8 of ASTM E-155



Macrograph of Cross Section AA Exposing the Flaw  
4X Magnification - Unetched

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Samples of aluminum and steel casting flaws most commonly experienced in production were selected to be radiographed in order to develop quantitative and descriptive picture images of various radiographic reference standards. Graphic illustrations of flaw size and flaw distribution for various radio- graphic reference standards were depicted by using radiographs and associated cross-sectional photo-macrographs. These graphic illustrations of radiographic levels of acceptance will provide meaningful design criteria for establishing (continued on reverse)		

20. ABSTRACT (continued)

realistic standards of acceptance for new material applications. This report also furnishes operational guidance to quality assurance and radiographic personnel in their normal on-the-job duties.